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Measurement of low-mass e^+e^- pair production in 1 and 2 *A* GeV C–C collision with HADES

M. Sudol[1,a], G. Agakishiev[2], C. Agodi[3], A. Balanda[4,b], G. Bellia[3,c], D. Belver[5], A. Belyaev[6], J. Bielcik[7], A. Blanco[8], A. Bortolotti[9], J.L. Boyard[1], P. Braun-Munzinger[7], P. Cabanelas[5], S. Chernenko[6], T. Christ[10], R. Coniglione[3], M. Destefanis[2], J. Díaz[11], F. Dohrmann[12], I. Durán[5], A. Dybczak[4], T. Eberl[10], L. Fabbietti[10], O. Fateev[6], R. Ferreira-Marques[8,d], P. Finocchiaro[3], P. Fonte[8,e], J. Friese[10], I. Fröhlich[13], T. Galatyuk[7], J.A. Garzón[5], R. Gernhäuser[10], A. Gil[11], C. Gilardi[2], M. Golubeva[14], D. González-Díaz[7], E. Grosse[12], F. Guber[14], M. Heilmann[13], T. Heinz[7], T. Hennino[1], R. Holzmann[7], A. Ierusalimov[6], I. Iori[9,f], A. Ivashkin[14], M. Jurkovic[10], B. Kämpfer[12], K. Kanaki[12], T. Karavicheva[14], D. Kirschner[2], I. Koenig[7], W. Koenig[7], B.W. Kolb[7], R. Kotte[12], A. Kozuch[4,b], A. Krása[15], F. Křížek[15], R. Krücken[10], W. Kühn[2], A. Kugler[15], A. Kurepin[14], J. Lamas-Valverde[5], S. Lang[7], J.S. Lange[2], K. Lapidus[14], L. Lopes[8], M. Lorenz[13], L. Maier[10], C. Maiolino[3], A. Mangiarotti[8], J. Marín[5], J. Markert[13], V. Metag[2], B. Michalska[9], J. Michel[13], E. Morinière[1], J. Mousa[16], M. Münch[7], C. Müntz[13], L. Naumann[12], R. Novotny[2], J. Otwinowski[4], Y.C. Pachmayer[13], M. Palka[7], Y. Parpottas[16], V. Pechenov[2], O. Pechenova[2], T. Pérez Cavalcanti[2], P. Piattelli[3], J. Pietraszko[7], V. Pospíšil[15], W. Przygoda[4], B. Ramstein[1], A. Reshetin[14], M. Roy-Stephan[1], A. Rustamov[7], A. Sadovsky[14], B. Sailer[10], P. Salabura[4], P. Sapienza[3], A. Schmah[10], C. Schroeder[7], E. Schwab[7], R. Simon[7], Yu.G. Sobolev[15], S. Spataro[2], B. Spruck[2], H. Ströbele[13], J. Stroth[13,7], C. Sturm[13], A. Tarantola[13], K. Teilab[13], P. Tlustý[15], M. Traxler[7], R. Trebacz[4], H. Tsertos[16], V. Wagner[15], M. Weber[10], M. Wisniowski[4], T. Wojcik[4], J. Wüstenfeld[12], S. Yurevich[7], Y. Zanevsky[6], P. Zhou[12], P. Zumbruch[7]

[1]Institut de Physique Nucléaire (UMR 8608), CNRS/IN2P3—Université Paris Sud, 91406 Orsay Cedex, France
[2]II. Physikalisches Institut, Justus Liebig Universität Giessen, 35392 Giessen, Germany
[3]Istituto Nazionale di Fisica Nucleare–Laboratori Nazionali del Sud, 95125 Catania, Italy
[4]Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
[5]Departamento de Física de Partículas, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain
[6]Joint Institute of Nuclear Research, 141980 Dubna, Russia
[7]Gesellschaft für Schwerionenforschung mbH, 64291 Darmstadt, Germany
[8]LIP-Laboratório de Instrumentação e Física Experimental de Partículas, 3004-516 Coimbra, Portugal
[9]Istituto Nazionale di Fisica Nucleare, Sezione di Milano, 20133 Milano, Italy
[10]Physik Department E12, Technische Universität München, 85748 Munich, Germany
[11]Instituto de Física Corpuscular, Universidad de Valencia-CSIC, 46971 Valencia, Spain
[12]Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany
[13]Institut für Kernphysik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt, Germany
[14]Institute for Nuclear Research, Russian Academy of Science, 117312 Moscow, Russia
[15]Nuclear Physics Institute, Academy of Sciences of Czech Republic, 25068 Rez, Czech Republic
[16]Department of Physics, University of Cyprus, 1678 Nicosia, Cyprus

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Abstract HADES is a secondary generation experiment operated at GSI Darmstadt with the main goal to study dielectron production in proton, pion and heavy ion induced reactions. The first part of the HADES mission is to reinvestigate the puzzling pair excess measured by the DLS collaboration in C + C and Ca + Ca collisions at 1 *A* GeV. For this purpose dedicated measurements with the C + C system at 1 and 2 *A* GeV were performed. The pair excess above a cocktail of free hadronic decays has been extracted and compared to the one measured by DLS. Furthermore, the excess is confronted with predictions of various model calculations.

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[a] e-mail: sudol@ipno.in2p3.fr

[b] Also at Panstwowa Wyzsza Szkola Zawodowa, 33-300 Nowy Sacz, Poland

[c] Also at Dipartimento di Fisica e Astronomia, Università di Catania, 95125 Catania, Italy

[d] Also at Universidade de Coimbra, Coimbra, Portugal

[e] Also at ISEC Coimbra, Coimbra, Portugal

[f] Also at Dipartimento di Fisica, Università di Milano, 20133 Milano, Italy

1 Introduction

An enhanced yield of dileptons with masses below the vector meson pole mass appears to be a general feature of heavy-ion reactions. This enhancement is defined as the excess of the measured signal pair yield over the summed-up cocktail of dileptons from long-lived sources.

We report here on a measurement of dilepton production in $^{12}C+^{12}C$ collisions at 1 *A* GeV and 2 *A* GeV with the High Acceptance DiElectron Spectrometer HADES. Our results, together with the findings of the former DLS experiment, allow to discuss the beam-energy dependence of the pair yield. In particular, our results from $^{12}C+^{12}C$ at 1 *A* GeV offer the possibility for a direct comparison with DLS. In this respect the long-standing so-called "DLS puzzle" can be addressed.

2 HADES experiment

The HADES spectrometer Fig. 1, described in detail in [1], consists of a 6-coil toroidal magnet centered on the beam axis and six identical detection sections located between the coils and covering polar angle $18° < \theta < 85°$. In the measurements presented here, each sector was composed of a gaseous Ring-Imaging Cherenkov detector, two inner planes of Mini-Drift Chambers before and after magnetic field for track reconstruction and a Time-Of-Flight wall supplemented at forward polar angles with Pre-SHOWER chambers. The interaction time was obtained from a fast diamond start detector located upstream of the target.

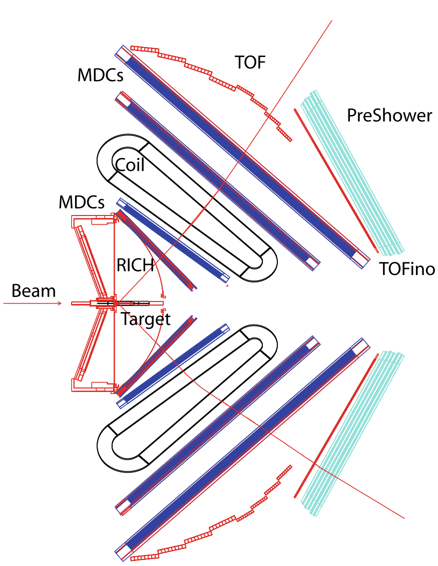

Fig. 1 Side view of the HADES detector at GSI

3 Data analysis

In the pair analysis [2, 3], opposite- sign pairs (e^+e^-), as well as like-sign pairs ($e^+\ e^+$ and $e^-\ e^-$) were formed and an opening-angle cut of $\theta_{ee} > 9°$ was used. From the reconstructed distributions, the combinatorial background (CB) was formed. For masses $M_{ee} > 0.2$ GeV/c^2, where statistics is small, the CB was obtained by an event-mixing procedure. Detector and reconstruction efficiencies, as well as the acceptance were taken into account. The measured electron pair yields were normalized to the number of neutral pions ($N_{\pi^0} = 1/2(N_{\pi^+} + N_{\pi^-})$) produced in the same event sample and extrapolated to 4π solid angle (Table 1). This way of normalizing the pair spectra compensates to first order the bias caused by the implicit centrality selection of our trigger. Indeed, simulation based on UrQMD events show that LVL1 events have an average number pf participating nucleons $A_{part} = 8.6$, instead of 6 for true minimum-bias events [5]. The results from the pion analysis are in agreement with the TAPS [7] as well as KaoS [9] data.

Measured pair signal distributions for 1 *A* GeV (Fig. 2) and 2 *A* GeV (Fig. 3) are compared to a pair cocktail A calculated from the long-lived components: π^0-Dalitz, η-Dalitz, ω-Dalitz and ω-Direct. Aims of this cocktail is to represent all contributions from decay of mesons in vacuum after the chemical and thermal freeze-out of the fireball. While the π^0 and the η are directly constrained by published

Table 1 The obtained pion multiplicity per participant nucleon. The systematic error of the yields is estimated to be 15% due to efficiency/purity corrections, the extrapolation to full solid angle and full kinematic phase space, and the determination of the number of participating nucleons

E_b [*A* GeV]	M_π/A_{part}
1.0	0.153 ± 0.023
2.0	0.061 ± 0.009

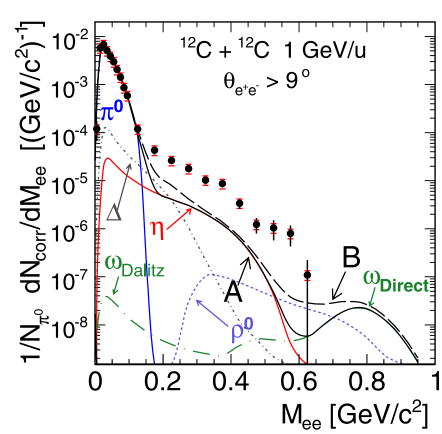

Fig. 2 HADES dilepton mass spectrum from $^{12}C + ^{12}C$ at 1 *A* GeV compared with cocktails *A* and *B* (see [3] for details)

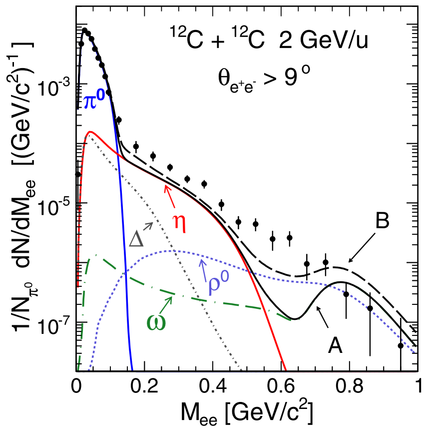

Fig. 3 HADES dilepton mass spectrum from ^{12}C+^{12}C at 2 *A* GeV compared with cocktails *A* and *B* (see [2] for details)

data [7, 9] with uncertainties of 10% (π^0) and 25% (η), the multiplicities of the ω meson is taken from an $m_\perp$-scaling ansatz [10].

In the used event generator (PLUTO [11, 12]) meson production was hence modeled assuming emission from a thermal source with a temperature $T = 80$ MeV, but no radial expansion velocity. Furthermore, for the π^0 mesons, an anisotropic angular distribution of the type $dN/d\cos\theta_{CMS} \sin 1 + a_2 \cos^2\theta_{CMS}$ with $a_2 = 0.7$ was used, as deduced from the HADES charged-pion analysis [4].

Cocktail A is clearly not sufficient to explain the HADES dilepton yields at intermediate, as well as for high masses. For masses below 0.15 GeV/c^2 one can observe good agreement between the data and the simulated cocktails A, as expected from the way, the spectra are normalized (assuming that no other source has a large contribution in this region). However in the η region the data shows a strong excess and therefore requires additional sources. Indeed, such contributions are expected from the decay of short-lived resonances, mainly from the $\Delta(1232)$ and the ρ, excited in the early phase of the collision. To include into the cocktail B pairs from $\Delta^{0,+-} \to Ne^+e^-$ decays, we assumed that the Δ yield scales with the π^0 yield and employed a calculated decay rate [13]. To add the ρ meson we used a similar prescription as for the ω. The full thermal cocktail B is shown as well in Figs. 2 and 3 as a long-dashed line. As it was expected, above the π^0 mass region the yield is larger but the data are still not reproduced fully.The calculation rather stays well below the data up to 0.7 GeV/c^2, where the main contributions are expected to come from two-body vector meson decays.

Furthermore, the excess of the experimental data can be quantified relative to the invariant mass taking into account only cocktail A. Figure 4 shows the ratio obtained in this way as a function of the invariant mass. The ratio is basically unity at low masses, where the main contribution comes from the π^0 Dalitz decay, as it was expected from the normalization. At higher masses the ratio of data and cocktail A develops a pronounced maximum mainly due to the lack of rho decay in the reference cocktail A. At intermediate masses ($0.15 < M_{ee} < 0.5$ GeV/c^2) the ratio is with invariant mass and deviated from unity.

It is clearly visible that the data at 1 *A* GeV shows a stronger excess in comparison to the data at 2 *A* GeV. A more detailed analysis [3] shows that the excess of the yield in this region scales with the beam energy as pion pro-

Table 2 Dilepton excess factor (Y_{exc}) in the pair mass range $0.15 < M_{ee} < 0.50$ GeV/c^2 as a function of beam energy (E_b). Errors given from left to right are statistical, systematical and due to the η multiplicities

E_b [*A* GeV]	Y_{exc}
1.0 (HADES)	$6.8 \pm 0.6 \pm 1.3 \pm 2.0$
1.04 (DLS)	$6.5 \pm 0.5 \pm 2.1 \pm 1.5$
2.0 (HADES)	$1.9 \pm 0.2 \pm 0.3 \pm 0.3$

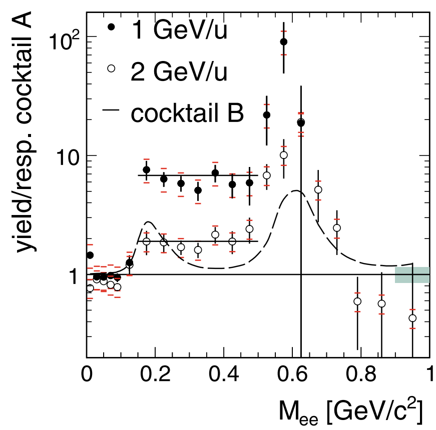

Fig. 4 Ratio of the experimental yield and cocktail A for 2 *A* GeV (*open symbols*) and 1 *A* GeV (*full symbols*). Statistical and systematic errors are displayed as vertical and horizontal bars, respectively. The *shaded area* depicts a 15% normalization error

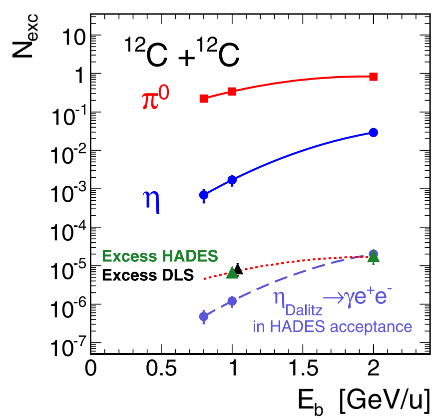

Fig. 5 Excess over cocktail A compared to the measured multiplicities of η and π^0 [7, 8] as a function of beam energy

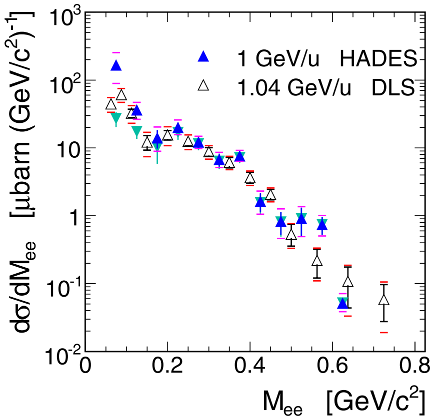

Fig. 6 Direct comparison of the dielectron cross sections measured in $^{12}C + ^{12}C$ at 1 *A* GeV by HADES and at 1.04 *A* GeV by DLS [5]. Invariant-mass distributions are compared within the DLS acceptance. The HADES data corresponding to the two fit forms discussed in details in [3] are shown as *upright* and *reverted full triangles*

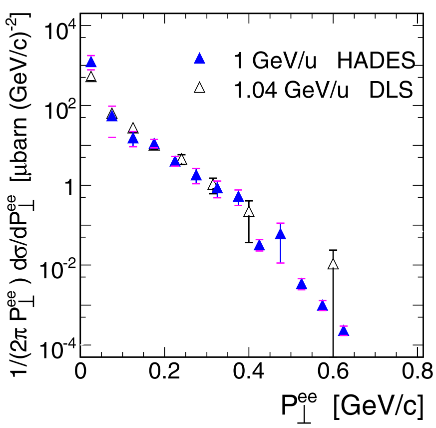

Fig. 7 Comparison of the $P_\perp$ distributions between DLS [6] and HADES mapped data

duction. This finding is illustrated in Fig. 5, which shows the energy scaling of the excess yield together with the behavior of η and π^0 production. It suggests that the pair excess is indeed driven by pion dynamics. From Fig. 5 it is also clear that the HADES data at 1 *A* GeV (green triangle) and DLS at 1.04 *A* GeV (black triangle) show the same excess.

A more detail comparison of the experimental results from HADES and DLS has been performed [3]. This was possible by mapping of the measured HADES pair yield onto the DLS acceptance. However the acceptance of both experiments do not overlap fully, especially in the π^0 mass region ($M < 0.15$ GeV/c^2) and at low pt. In the discussed excess region the HADES acceptance almost fully contains the DLS one. Additionally, a conversion of multiplicities, measured by HADES, into the production cross section given by DLS needs to be done. This way of mapping allows for a model-independent comparison of the two data sets. Figures 6 and 7 show HADES mapped data together with the published DLS $d\sigma/dM_{ee}$ [5] and $1/(2\pi p_\perp)\, d\sigma/dp_\perp$.

It is apparent that, within statistical and systematic uncertainties, both measurements are in very good agreement, in particular in the region of excess yield. The same conclusion is obtained from the comparison of the $P_\perp$ distributions (Fig. 7).

4 Conclusion

In summary, we report the measurement of inclusive dilepton pair production in $^{12}C+^{12}C$ at beam energies 1 and 2 *A* GeV. Both data show agreement with the known π^0 production. In the mass region $0.15 < M_{ee} < 0.5$ GeV/c^2 data show a excess above the known η-Dalitz rate production by a factor of 2 and 7 for 1 *A* GeV and 2 *A* GeV, respectively. This pair yield excess is consistent with that measured by the DLS. In addition, the excess scales with the beam energy like pion production. For better understanding of the observed excess other HADES results on dilepton production in a elementary reactions will add important information. Furthermore a direct comparison between HADES and DLS results has been presented. It is clear, that within statistical and systematical errors both experiments show agreement, in particular in the excess region. This agreement indicates that the experimental side of the DLS puzzle is cleared up and that a final solution can come only with more theoretical input.

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References

1. G. Agakishiev et al., Nucl. Instrum. Methods A, to be submitted. arXiv:0902.4377v1 [nucl-ex]
2. G. Agakichiev et al., Phys. Rev. Lett. **98**, 052302 (2007)
3. G. Agakishiev et al., Phys. Lett. B **663**, 43 (2008)
4. G. Agakishiev et al., Eur. Phys. J. A, submitted. arXiv:0902.3478 [nucl-ex]
5. R.J. Porter et al., Phys. Rev. Lett. **79**, 1229 (1997)
6. J. Carrol et al., contribution to the Int. Workshop on Soft Dileptons, LBNL, Berkeley (1997)
7. R. Averbeck et al., Z. Phys. A **359**, 65 (1997)
8. R. Holzmann et al., Phys. Rev. C **56**, R2920 (1997)
9. F. Laue et al., Eur. Phys. J. A **9**, 397 (2000)
10. E.I. Bratkovskaya et al., Phys. Lett. B **424**, 244 (1998)
11. M.A. Kagarlis, GSI Report No. 2000-03 (2000)
12. I. Froelich et al., PoS **ACAT2007**, 076 (2007)
13. C. Ernst et al., Phys. Rev. C **58**, 447 (1998)